

## ADVANCED TERRAIN ANTI-COLLISION DEVICE

### CROSS - REFERENCE TO RELATED APPLICATIONS

The present Application is based on International Application No.  
5 PCT/EP2004/053325, filed on December 8, 2004, which in turn corresponds  
to FR 03/15022 filed on December 19, 2003, and priority is hereby claimed  
under 35 USC §119 based on these applications. Each of these applications  
are hereby incorporated by reference in their entirety into the present  
application.

### 10 BACKGROUND OF THE INVENTION

#### 1. Field of the invention

The field of the invention is that of onboard terrain anticollision  
15 systems for aircraft.

#### 2. Description of the prior art

Collisions with the terrain while the aircraft is fully controlled also  
called "CFIT", the acronym standing for "Controlled Flight Into Terrain", have  
20 been and still remain one of the main causes of air disasters. Developed  
some thirty years ago, the systems termed "GPWS", the acronym standing  
for "Ground Proximity Warning System", have allowed a significant reduction  
in the number of accidents. They are based on the use of radio-probes which  
make it possible to determine in an instantaneous manner the position of the  
25 aircraft with respect to the ground. These rudimentary and nonpredictive  
systems have not however made it possible to completely eliminate  
accidents of this type.

More recently, "GCAS" type systems, the acronym standing for  
"Ground Avoidance Collision System", have appeared. These systems rely  
30 on the use of systems for predicting potential trajectories of the craft and the

determination of possible collisions between these trajectories and the terrain. The pilot can thus anticipate a future collision and react accordingly.

More recently still, terrain anticollision systems have taken the generic term of "TAWS", the acronym standing for "Terrain Awareness  
 5 Warning System", and cover all systems possessing a function for predicting potential collisions with the terrain. These systems are defined by an international aeronautical standard, the TSO C151A, and fulfill in addition to the customary GPWS functions, the additional functions of predictive alert of risks of collision with the relief and/or obstacles on the ground termed  
 10 "FLTA", the acronym standing for "predictive Forward-Looking Terrain collision Awareness and alerting" and of premature descent termed "PDA", the acronym standing for «Premature Descent Alerting". These FLTA and PDA functions consist in warning the crew through timely prealerts or alerts whenever, under controlled flight, a situation of risk of collision with the  
 15 terrain arises, in particular when the short-term foreseeable trajectory of the aircraft encounters the relief and/or an obstacle on the ground, so that an avoidance maneuver is engaged. The pilot can thus avoid the "CFIT" by an appropriate avoidance maneuver. The basic maneuver is termed "pull-up" signifying vertical avoidance.

20 These functions can according to the implementation be grouped into a single mode termed "CPA", the acronym standing for "Collision Prediction and Alerting".

The first generation of "TAWS" systems affords the functions of  
 25 prediction of potential trajectories, of determination of risk of collision with the terrain, of cartographic display of the terrain comprising the indication of the risk of collision and of audible alerts in the event of risk of collision. Certain second-generation systems of the "TAWS" systems allow not only the prediction of the risk of collision with the terrain, but also alert the pilot as to  
 30 the feasibility of the disengagement maneuver to be performed to anticipate

this risk of collision. This is rendered possible by the use in real time of the upward speed capabilities of the aircraft.

In a more precise manner, the "CPA" mode is based on a  
 5 comparison between a surface also called the safety profile denoted S or  
 "clearance sensor" and the surface or the terrain profile situated under said  
 surface or said safety profile, said comparison taking account of a safety  
 margin. The terrain profile arises from a topographic representation extracted  
 from a terrain and/or obstacles database onboard the aircraft and is  
 10 correlated with the position of the aircraft by virtue of the position sensors of  
 the aircraft.

The safety surface or profile S are represented diagrammatically in  
 the two cross sections of Figure 1 which represent a lateral view and a view  
 from above of said surface or of said profile.

15 The intersection of said surface S with a vertical plane containing  
 the aircraft A forms a trajectory termed the predicted trajectory  $T_P$ . In Figure  
 1, the origin O of this predicted trajectory is taken under the aircraft, vertical  
 thereto and with a vertical safety margin MV whose value is determined as a  
 function of various parameters such as, for example, the flight phase, the  
 20 vertical speed of the aircraft, the distance to the closest airport or destination  
 airport. In a first variant of calculation of the "clearance sensor", the safety  
 margin is in an equivalent manner associated with the profile or with the  
 terrain surface. In this case, the origin O of the trajectory is taken at the level  
 of the aircraft, the origin of the terrain under the aircraft this time being  
 25 heightened by a vertical safety margin MV. It is possible, of course, to  
 combine in a second variant, the two modes of calculation of the "clearance  
 sensor", that is to say take the origin O of the trajectory under the aircraft with  
 a first margin and "raise up" the terrain by a second margin, the sum of these  
 two margins being equal to the safety margin MV.

This origin O determined, the predicted trajectory  $T_P$  comprises two main parts as is indicated in the lateral view of Figure 1 where the predicted trajectory appears in solid line:

- 5       • a first part corresponding to a first flight time  $T_1$ , dependent on a prediction of the trajectory in progress calculated on the basis of the origin O;
- 10       • a second part corresponding to a second flight time  $T_2$  following the first flight time  $T_1$ , dependent on a prediction of a vertical avoidance trajectory. The first part is calculated on the basis of flight parameters comprising the speed and the roll angles of the aircraft.

Generally, the flight time  $T_1$  is at least equal to the response time necessary for initializing a vertical avoidance maneuver.

15       The second part is also called "SVRMB", the acronym standing for "Standard Vertical Recovery Maneuver Boundary" . It models a lower limit of the standard vertical avoidance trajectory supposed to make it possible to avoid the collision with the terrain. The maneuver comprises, for the pilot, the following successive operations:

- 20       • Reducing the roll angle until horizontal stabilization of the aircraft. By way of example, the rate is 15 degrees per second;
- Pulling up the aircraft under a load factor compatible with the performance of the aircraft. By way of example, the load factor is 0.5 g;
- 25       • Maintaining the pull-up angle of the aircraft either with a standard slope equal to a certain percentage of the possible maximum slope of the aircraft, for example equal to 90 percent, or with a slope equal to the slope of the aircraft when it is already greater than said standard slope. The typical duration  $T_2$  of this phase is of the order of 112 seconds. This duration
- 30       can be modulated as a function of the proximity of the airport for certain mountainous zones or for other flight considerations.

The future trajectory  $T_F$  of the aircraft in the event of a vertical avoidance maneuver is depicted dashed in the lateral view of this figure.

The safety surface or profile are limited laterally by a left limit  $T_G$  and a right limit  $T_D$  as is seen in the view from above of Figure 1 where these  
 5 limits are depicted in solid line. These limits correspond to predicted limit trajectories of the aircraft during a flight duration corresponding to the sum of the first and second flight times  $T_1$  and  $T_2$ , said limits being defined essentially by a lateral margin  $ML$  taking its origin at the point  $O$  and at least  
 10 one angle of left lateral aperture  $\theta_G$  and at least one angle of right lateral aperture  $\theta_D$ , left and right being defined with respect to the sense of the trajectory of the aircraft.

The limits of the terrain situated under the aircraft used for the comparison with the safety surface or profile are obtained by the vertical projection of the left and right limits of the safety surface onto the terrain  
 15 situated under the aircraft.

The lateral margin  $ML$  taken in a horizontal plane passing through the origin  $O$  typically equals 100 meters on either side of the aircraft. The aperture angles can vary as a function of the forecast curvature of the future trajectory of the craft in a horizontal plane. Said trajectory is represented  
 20 dashed in Figure 1. On the convex side of the curvature, the angle of lateral aperture typically equals a few degrees. It is limited to a value of 90 degrees. On the opposite side, it typically equals 1.5 degrees. In Figure 1, the aircraft is turning to the right. Consequently, the angle of right lateral aperture  $\theta_D$  equals several degrees and the angle of left lateral aperture  $\theta_G$  equals 1.5  
 25 degrees. In this way, the surface situated between these two limits covers the whole zone capable of being overflown by the aircraft during a flight duration equal to the sum of the first flight time  $T_1$  and of the second flight time  $T_2$ .

Currently, the "CPA" mode calculates two safety surfaces or profiles, the first surface  $S_{MT}$  is called the medium-term safety Surface or  
 30 Profile or else the "Medium Term Clearance Sensor" and the second  $S_{CT}$  is

called the short-term safety Surface or Profile or else the "Short Term Clearance Sensor". These surfaces are represented in Figure 2.

The short-term safety surface or profile are calculated as indicated in the previous paragraphs.

5           The medium-term safety surface or profile comprise two parts. The first part can be determined in a similar way to the first part of the safety surface or of the short-term profile. The second part corresponds to a second surface or a second safety profile that can be built according to calculation principles similar to those of the short-term safety surface or profile but by  
10 taking the origin O' of said second surface no longer at the level of the aircraft A but on the predicted trajectory ahead of the aircraft. Typically, the first flight time  $T_1$  of the predicted trajectory of the medium-term safety surface or profile has a duration of about 20 seconds, the first flight time of the predicted trajectory of the short-term safety surface or profile has a  
15 duration of about 8 seconds. These values of 20 seconds and of 8 seconds can be modulated as a function of considerations such as the height of the aircraft above the ground, the air-speed of the aircraft, its vertical speed, the proximity of an airport, etc.

          The medium-term safety surface or profile  $S_{MT}$  is dedicated, in  
20 conjunction with the surface or the profile of the terrain, corresponding to the advanced detection of risk of collision with the terrain G as indicated in Figure 3. The risk of collision is depicted by a white star. In the event of risk of collision, a prealarm is emitted in audible and/or visual form. In this case, the potentially dangerous terrain is depicted typically in plain yellow on the  
25 displays of the instrument panel. The pilot can then evaluate the situation and rectify or otherwise his current trajectory.

          The short-term safety surface or profile  $S_{CT}$  is dedicated, in conjunction with the surface or the profile of the corresponding terrain, to the detection of risk of imminent collision with the terrain G as indicated in Figure  
30 4. In the event of risk of collision, an alarm is emitted in audible and/or visual form. This alarm is in the general case an alarm termed the vertical

avoidance alarm also called "pull-up". In this case, the dangerous terrain is typically depicted in plain red on the displays of the instrument panel. The pilot absolutely must instigate a vertical avoidance maneuver.

Nevertheless, in certain cases, the alarm associated with a vertical  
 5 avoidance is replaced by an alarm termed the transverse avoidance alarm also called "avoid terrain". These cases arise when a vertical avoidance trajectory would not make it possible to avoid the collision with the terrain, typically when starting a turn or stopping a turn in mountainous zones. The transverse avoidance must not, in these particular cases, limit itself to a  
 10 simple maneuver termed a vertical evade but also integrate a transverse component so as to avoid the collision, the maneuver rate being able to be provided by the TAWS system. In this case, the dangerous terrain is typically represented by alternately red and black bands on the displays of the instrument panel. The pilot absolutely must instigate a transverse avoidance  
 15 maneuver.

This "avoid terrain" alarm is triggered in certain specific situations detailed below:

- When the surface or the profile of the terrain situated in the safety surface or profile exceeds locally at one or more points  
 20 or in one or more sections in a very significant manner the level of said surface or of said safety profile. In this case, a vertical avoidance maneuver may prove to be insufficient to eliminate any risk of collision. This situation can occur when the craft A is at a significantly lower height than the surrounding terrain, for  
 25 example, when the craft is in the phase of approach to airports P situated in a mountainous zone as at Calvi, at Chambéry, at Katmandu, at Innsbruck, etc. This case is presented in the lateral and top views of Figure 5 where the future trajectory  $T_F$  of the aircraft A is depicted in solid line and the safety surface or profile S is depicted dashed.  
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- 5                      • When a very wide portion of the surface or of the profile of the terrain enters the safety profile or surface. In this case also, it is not certain that a vertical avoidance maneuver will make it possible to preserve a sufficient vertical safety margin making it possible to avoid the collision. This situation is depicted in Figure 6.
- 10                    • When the aircraft A changes trajectory rapidly, either by increasing the curvature of its trajectory as indicated in Figure 7, or by decreasing it as indicated in Figure 8. In the views of these two figures, the position and the future trajectory  $T_F$  of the aircraft A have been indicated at the instants T and  $T+\Delta T$ . At the instant T, the future trajectory symbolized by an arrow did not foretell any collision with the terrain G. At the instant  $T+\Delta T$ , a change of trajectory gives rise to a risk of near collision.
- 15                    • When the pilot has not reacted sufficiently quickly to a vertical avoidance alarm.

The transverse avoidance maneuver consists either in carrying out a vertical avoidance maneuver accompanied by a turn with an appropriate radius of deflection, or else in a correction of the last piloting action performed by the pilot to obtain the necessary trajectory correction.

One of the tricky points in the management of "TAWS" systems is to precisely determine the situations in which the transverse avoidance alarm termed "avoid terrain" must be triggered, simple comparison between the medium- and short-term safety surfaces or profiles and the surfaces or terrain profiles possibly proving to be insufficient in the specific situations mentioned above.

Specifically with such a comparison, the height of overshoot of the terrain above the safety surface is not established.



## SUMMARY OF THE INVENTION

5           The invention proposes to consider in addition to the safety surfaces or profiles ordinarily calculated a surface or a profile called the immediate safety surface or profile or else the "Immediate Clearance Sensor" making it possible to discern with greater exactness the type of alarm and maneuver to be performed. Such an invention makes it possible to provide  
10 alarms appropriate to the situation and hence to thus decrease in an appreciable manner the risk of collision with the terrain.

More precisely, the invention is aimed at an onboard terrain anticollision device for aircraft comprising at least:

- 15           • A memory comprising topographic data of the terrain and/or of the obstacles overflown;
- Information processing means comprising:
  - o An input for receiving flight parameters;
  - o First trajectory prediction means for establishing on the  
20 basis of said flight parameters at least one first profile or a first safety surface corresponding to a first predicted trajectory;
  - o First means of topographic calculation for establishing on the basis of said flight parameters at least one first profile  
25 or a first topographic surface constituted on the basis of the topographic data of the terrain and/or of the obstacles overflown;
  - o First comparison means for establishing at least one first comparison between said first profile or said first safety  
30 surface and a first profile or a first topographic surface for

determining at least one first risk of collision of the aircraft with the ground;

- 5                   ○ Second trajectory prediction means for establishing on the basis of the flight parameters a second profile or a second safety surface corresponding to a second predicted trajectory;
- 10                  ○ Second calculation means for establishing on the basis of the flight parameters a second profile or a second topographic surface constituted on the basis of the topographic data of the terrain and/or of the obstacles overflow;
- 15                  ○ Second comparison means for establishing a second comparison between said second profile or said second safety surface and the second profile or the second topographic surface for determining a second risk of collision of the aircraft with the ground;
- 20                  • Alarm means linked to said processing means for establishing at least one first state termed the first alarm state as a function of the results of the first comparison and a second state termed the second alarm state as a function of the results of the second comparison, said second state different from the first alarm state.

Advantageously, the device also comprises:

- 25                  • Information processing means comprising:
 
  - 30                   ○ Third trajectory prediction means for establishing at least on the basis of the flight parameters a third profile or a third safety surface corresponding to a third predicted trajectory;
  - Third means of topographic calculation for establishing at least on the basis of said flight parameters a third profile

or a third topographic surface constituted on the basis of the topographic data of the terrain and/or of the obstacles overflown;

- 5                   ○ Third comparison means for establishing at least one third comparison between said third profile or said third safety surface and a third profile or a third topographic surface for determining at least one third risk of collision of the aircraft with the ground;
- 10               • Alarm means linked to said processing means for establishing at least one state termed the prealarm state as a function of the results of the third comparison.

#### BRIEF DESCRIPTION OF THE DRAWINGS

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The invention will be better understood and other advantages will appear on reading the description which will follow given without limitation and by virtue of the appended figures among which:

- 20               • Figure 1 represents a lateral view and a view from above of the safety surface according to the prior art;
- Figure 2 represents a view from above of a short-term defined safety surface and of a medium-term defined safety surface;
- Figure 3 represents the comparison between the medium-term safety surface and the surface of the terrain;
- 25               • Figure 4 represents the comparison between the short-term safety surface and the surface of the terrain;
- Figure 5 represents a first situation triggering an alarm and a transverse avoidance maneuver;
- 30               • Figure 6 represents a second situation triggering an alarm and a transverse avoidance maneuver;

- Figure 7 represents a third situation triggering an alarm and a transverse avoidance maneuver;
- Figure 8 represents a fourth situation triggering an alarm and a transverse avoidance maneuver;
- 5     • Figure 9 represents the medium-term safety surface, the short-term safety surface and the immediate safety surface according to the invention.

#### MORE DETAILED DESCRIPTION

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The onboard terrain anticollision device hence comprises a "CPA" mode generating at least:

- a medium-term safety surface or profile  $S_{MT}$  also called the "Medium Term Clearance Sensor"
- 15     • and/or a short-term safety surface or profile  $S_{CT}$  also called the "Short Term Clearance Sensor"
- and a safety surface or profile termed immediate  $S_I$  according to the invention also called the "Immediate Clearance Sensor"

20     The medium-term safety Surface or Profile  $S_{MT}$  is dedicated to the detection of a potential collision with the terrain in the medium term. In the event of risk of collision, a prealarm is emitted in such a way that the pilot takes cognizance of the risk and can anticipate this danger.

25     The short-term safety surface  $S_{CT}$  is dedicated to the detection of a potential collision with the terrain in the short-term. In the event of risk of collision, a first alarm is emitted indicating to the pilot that he must instigate forthwith a vertical avoidance maneuver termed "pull-up".

30     The safety surface or profile termed immediate  $S_I$  is dedicated to the detection of a potential collision with the terrain in the very short term, which collision may not be avoided by a simple vertical avoidance maneuver. In the event of risk of collision, a second alarm is emitted for transverse

avoidance termed "avoid terrain", noticeably different from the alarm termed "pull-up". In the majority of cases, the pilot must then instigate either a transverse avoidance maneuver or a cancellation of the trajectory correction having led to this situation.

5           The calculation of this immediate safety surface or profile makes it possible to discriminate the situations where a "pull-up" maneuver is sufficient for avoiding the collision from the situations where an "avoid terrain" maneuver is imperative for avoiding the collision, this discrimination being ensured neither by first-generation "TAWS" systems, nor in a fully  
10       satisfactory manner by second-generation "TAWS" systems.

          Consequently, the first alarm is of the vertical avoidance alarm type and the second alarm is of the transverse avoidance alarm type, the vertical avoidance alarm corresponding for the pilot to a vertical avoidance maneuver and the transverse avoidance alarm corresponding for the pilot to  
15       a transverse avoidance maneuver.

          The medium-term, short-term and immediate safety surfaces or profiles are defined as previously as a function of a predicted trajectory bounded by two lateral limits. Each of the predicted trajectories comprises two parts:

- 20           • a first part corresponding to a first flight time, dependent on a prediction of the trajectory in progress calculated on the basis of an origin O taken at the level of the aircraft;
- a second part corresponding to a second flight time  $T_1$  following the first flight time, dependent on a prediction of a vertical  
25       avoidance trajectory.

          The parameters defining the first part or the second part of the predicted trajectory of the immediate safety surface can be substantially different from the parameters defining the other safety surfaces. In particular, the vertical safety margin can have a different value, in general lower than  
30       the vertical margins used with the "Short Term Clearance Sensor" and "Medium Term Clearance Sensor" type surfaces.

The first flight time for the medium-term safety surfaces or profiles has a duration of about 20 seconds, the first flight time for the short-term safety surface or profile has a duration of about 8 seconds and the first flight time for the immediate safety surface or profile has a low duration, typically  
 5 less than 3 seconds.

The first, the second and the third safety surface or profiles are bounded laterally by a left limit and a right limit, said limits being defined essentially by a lateral margin and at least one angle of left lateral aperture and at least one angle of right lateral aperture.

10 The parameters defining the immediate safety surface or profile  $S_i$  termed the "Immediate Clearance Sensor" according to the invention can be neighboring or identical with those defining the medium-term and short-term safety surface or profile. To optimize the effectiveness of said immediate safety surface or profile, the lateral margins or the angles of right and left  
 15 lateral aperture of the limits of said immediate safety surface or profile can also be substantially different from the lateral margins or from the angles of right and left lateral aperture of the limits of the other predicted surfaces. To improve the effectiveness of the system according to the invention, at least one of the first comparison means or second comparison means can  
 20 advantageously comprise a criticality indicator of the risk of collision with the terrain. Said criticality indicator can depend on the surface or on the terrain profile situated above one of the safety surfaces or profile. It can also depend on the terrain surface and on the terrain height situated above one of the safety surfaces.

25 The alarms are of audible or visual type. They can be indicated in the latter case on the displays of the instrument panel of the aircraft.

Advantageously, the information processing means can comprise means of alarm management as a function of the evolution of the risks of collision with the terrain.

30 The device then comprises means for switching the transverse avoidance and vertical avoidance alarms, when the situation of the aircraft

evolves. Specifically, the alarms provided by devices of this type are typically maintained so long as the situation of danger of collision is not resolved.

In order to avoid unscheduled switchings, such a switching can typically be performed when the situation of the aircraft has changed in a significant manner and the trajectory has evolved noticeably, for example by  
5 a change of the slope or of the roll or of the heading of more than a few degrees, typically from 2 to 10 degrees.